Power Conversion System Architectures

For Grid Tied Energy Storage

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Outline

1. Power Conversion System (PCS)
   – Overview and Purpose

2. Conversion Topologies
   – Single Stage three-legged IGBT based inverters
   – Multi-stage converters
   – Inverter Operation
   – Advanced Topologies
     • Multi-level inverters
     • Z-inverters
   – Multiple Module Topologies

3. Application Topics
   – Increasing Power Levels
     • Line Commutated Inverters
   – Islanding methods
   – Phase Configuration
   – Transformers for Energy Storage Systems (ESS)
   • Output power compliance
Grid Tied Energy Storage mediums are predominately direct current (DC) in nature. To effectively utilize the energy storage capacity on the present electric utility grid, the energy must be converted to a standard Alternating Current (AC) level and regulated through a converter.

Converter Purpose and Control:

- Bi-directional conversion from AC to DC and DC to AC.
- AC Grid to DC Storage isolation and protection
- Interconnection and control of multiple DC Sources
- Regulated, stable and controllable power flow

Control Modes

- AC current \((P,Q)\) – Standard Grid Tied Operation
- AC Voltage \((V,F)\) – Islanded Operation
- DC current \((I_{DC})\) – Grid Tied, Battery Charge/Formation
- DC Voltage \((V_{DC})\) – Grid Tied, Battery Conditioning
Basic AC/DC Power Conversion Topologies

**Single Stage Converters**
- Limited to DC Voltages > 1.5X VAC_{RMS}
- Maximum Efficiency

**Multi-Stage Converters**
- Maximum DC Voltage Range
- Increased Losses
- Increased hardware Cost
Single Stage Inverter

Primary Sub-Sections

DC Energy Storage

DC/AC Bi-directional Inverter

Step-Up Transformer

Medium Voltage Interconnection

[Diagram of power conversion system]

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Basic Inverter Operation

• Operation
  – Sinusoidal Pulse Width Modulation
  – Phase locked to Grid
  – Reference signal provided to compare with triangle waveform
  – Gates are triggered as output of controller
  – Modulation is provided to control power
  – Output is filtered to provide limited harmonics/switching noise
Advanced AC/DC Power Conversion Topologies

- Multi-Port, Multi-Stage Converter
  - Optimized for renewable integration with energy Storage
Other Advanced Inverter Topologies

- **Z-inverter**
  - Accommodates reduced DC voltages (boost DC > AC)
  - Inherently protected by limiting DC current

- **Multi-level inverters**
  - Increased DC and AC voltages
  - Reduced Losses
  - Reduced Harmonics, smaller filters
  - Requires special $V_{iso}$ IGBTS
    (Diode Clamped, Flying Capacitor and Cascade Multi-Level Cell)
Independent Phase Control Systems

- Independent Phase control
  - 240 VAC Split Phase
  - Three Phase systems
  - Grid Stabilization and Balancing
  - Single or independent Battery strings
Multiple Module Topology

- For Multi-MegaWatt Systems
- Redundant Parallel N+1 Configurations
- Synchronous and Interleaved Switching
- Independent Battery Strings

![Diagram of Power Conversion System Architectures](image_url)
Increasing Power Levels for ESS

Parallel, Multi-module IGBT based Inverter Systems
- Sub-Cycle response
- True 4 quadrant operation
- Low harmonic levels

Thyristor Based Line Commutated (Cycloconverter) Systems
- Reduced cost per $/MW
- Limited power factor control
- Large AC Filters Required
- Increased Response Time
- Hybrid Systems

1.5MW Inverters installed at Xtreme Power BESS in Hawaii

5/24/2012 Power Conversion System Architectures
For Grid Tied Energy Storage
ESS Islanding Methods

Offline ESS with Dynamic Transfer (Islanding)
- Maximum Efficiency
- Minimum components
- Minimum Losses

Online Double Conversion
- Limited to PCS Power to load
- 2X conversion losses
- Increased Complexity
Phase Configuration

Single Phase Systems
- Simple topology and control
- Low Power & Voltage
- High DC ripple voltage/current or increased filtering required
- Higher semiconductor current

Three Phase Systems
- Simple integration to Utility Grid
- Medium to High Power
- Reduced DC Ripple voltage/current
- Lower semiconductor current

![Graphs showing AC voltage for single and three-phase systems]
Transformers for ESS

Types of Transformers

- Vacuum Pressure Impregnated (VPI)
- Oil Immersed
- Cast Coil

Transformer Configurations

- Single winding
- Multiple LV Windings
Output Protection and Power Quality Assurance

Voltage and Frequency Protection IEEE 1547

Output Power Quality

Table 3—Maximum harmonic current distortion in percent of current (I)\textsuperscript{a}

<table>
<thead>
<tr>
<th>Individual harmonic order h (odd harmonics)\textsuperscript{b}</th>
<th>h &lt; 11</th>
<th>11 (\leq) h &lt; 17</th>
<th>17 (\leq) h &lt; 23</th>
<th>23 (\leq) h &lt; 35</th>
<th>35 (\leq) h</th>
<th>Total demand distortion (TDD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent (%)</td>
<td>4.0</td>
<td>2.0</td>
<td>1.5</td>
<td>0.6</td>
<td>0.3</td>
<td>5.0</td>
</tr>
</tbody>
</table>

\textsuperscript{a} I = the greater of the Local EPS maximum load current integrated demand (15 or 30 minutes) without the DR unit, or the DR unit rated current capacity (transformed to the PCC when a transformer exists between the DR unit and the PCC).

\textsuperscript{b} Even harmonics are limited to 25\% of the odd harmonic limits above.
Conclusions

• Power Conversion is an integral part of Energy Storage Systems
• Limit Conversion Stages to maximize efficiency and minimize complexity
• Integrate systems as soon as practicable to avoid grid interaction and maximize efficiency
• Modularized systems offer unique advantages in redundancy and expandability
• Advanced and hybrid topologies may offer the best solution for specific ESS Challenges
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Established 1963; Manufacturer of Solid State Power Conversion equipment, Battery Management Systems, VPI, Cast and Oil filled Transformers and DC Power Supplies.